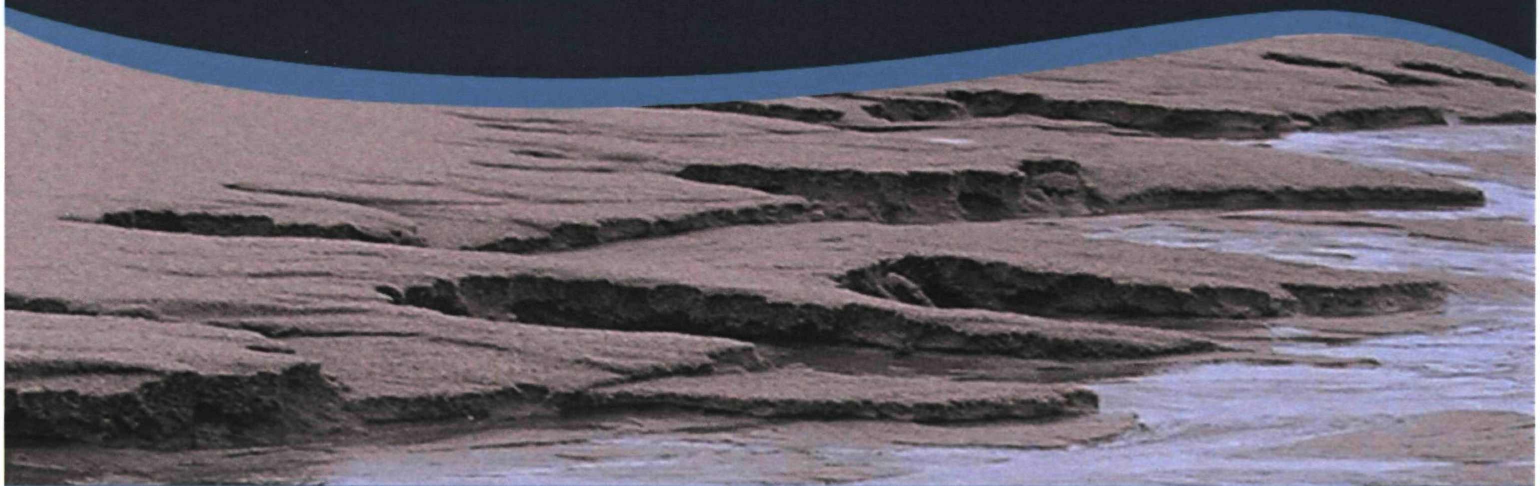

DRAFT DIOXIN TREATABILITY STUDY LITERATURE REVIEW
SAN JACINTO RIVER WASTE PITS SUPERFUND SITE

Prepared for

McGinnes Industrial Maintenance Corporation

International Paper Company

U.S. Environmental Protection Agency, Region 6

Prepared by

Anchor QEA, LLC

614 Magnolia Avenue

Ocean Springs, Mississippi 39564

October 2011

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LIST OF ACRONYMS AND ABBREVIATIONS

2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
2,3,7,8-TCDF	2,3,7,8-tetrachlorodibenzofuran
AC	Activated Carbon
Anchor QEA	Anchor QEA, LLC
AOC	Administrative Order on Consent
APEG	Alkaline Polyethylene Glycolate
BCD	Base-Catalyzed Decomposition
BMPs	best management practices
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CETCO	Colloid Environmental Technologies Company
CF	cubic feet
CFR	Code of Federal Regulations
COI	Chemical of Interest
COPC	contaminant of potential concern
cy	cubic yard
FRTR	Federal Remediation Technologies Roundtable
I-10	Interstate Highway 10
IBTD	In-Barge Thermal Desorption
Integral	Integral Consulting Inc.
IPC	International Paper Company
IPTD	In-Pile Thermal Desorption
ISTD	In Situ Thermal Desorption
K_{oc}	organic carbon partitioning coefficient
K_{ow}	octanol/water partitioning coefficient
KPEG	Potassium Polyethylene Glycolate
LLDPE	linear low density polyethylene
MIMC	McGinnes Industrial Maintenance Corporation
ng/kg	nanograms per kilogram
NPL	National Priorities List
OTA	Office of Technology Assessment
PCB	polychlorinated biphenyl

PIC	products of incomplete combustion
ppm	parts per million
RACR	Removal Action Completion Report
RAWP	Removal Action Work Plan
RCRA	Resource Conservation and Recovery Act
RCM	Reactive Core Mat®
RI/FS	Remedial Investigation and Feasibility Study
River	San Jacinto River
S/S	Solidification/Stabilization
SET	Solvated Electron Technology™
sf	square foot
Site	San Jacinto River Waste Pits Superfund Site
SOW	Statement of Work
sy	square yard
TCRA	time critical removal action
TEQ	toxic equivalency
UAO	Unilateral Administrative Order
U.S.	United States
USEPA	U.S. Environmental Protection Agency
UV	ultraviolet
Veolia	Veolia Environmental Services

1 INTRODUCTION

1.1 Purpose

This document fulfills the requirement for a "Literature Survey and Determination of the Need for Treatability Testing" that is contained in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Section 106(a) Unilateral Administrative Order (UAO) issued by the U.S. Environmental Protection Agency, Region 6 (USEPA), Docket No. 06-03-10, to McGinnes Industrial Maintenance Corporation (MIMC) and International Paper Company (IPC). The requirement is part of Task 8 in the Statement of Work (SOW) of the UAO for the San Jacinto River Waste Pits Superfund Site (Site) Remedial Investigation and Feasibility Study (RI/FS). The SOW requires that the Respondents evaluate the performance, relative costs, applicability, removal efficiencies, operation and maintenance requirements, and implementability of treatment options and assess whether sufficient information about candidate technologies is available to evaluate them in the RI/FS or whether treatability studies are necessary to perform the evaluation.

This document does <u>not</u> contain an evaluation of remedial alternatives for the Site. The evaluation of remedial alternatives is the subject of the FS. Rather, the purpose of this evaluation is to identify treatment technologies that are potentially applicable as part of a remedy for the Site, and review currently available information about each treatment technology to determine whether the available information is sufficient for the needs of the FS. The FS will provide an evaluation of remedial alternatives that incorporate both treatment and non-treatment technologies to mitigate threats to human health and the environment from the Site, and is scheduled to be delivered to USEPA on February 21, 2013.

The FS will require sufficient information about the long- and short-term effectiveness, implementability, and cost of each treatment technology to evaluate the relative cost effectiveness of the remedial alternatives. Additional information on treatment technologies may be needed for application of the method, such as operational requirements and certain performance metrics. This type of detailed information may be obtained from treatability studies during the design phase, after the remedy is selected and may not be needed for the FS evaluation.

Candidate technologies are identified in this document as 1) inapplicable to the Site (with the rationale provided), 2) applicable with sufficient information available to evaluate in the FS, or 3) potentially applicable with additional information required to complete the FS evaluation. As required by the UAO, and as appropriate, this document will only recommend the performance of treatability tests for technologies that fall into the third category (potentially applicable, but with insufficient information available to evaluate in the FS).

The following sections present information concerning available treatment methods and their applicability to the Site. This evaluation provides a review of technologies available for the treatment of sediment and sludge containing dioxins and other Site contaminants of potential concern (COPCs). Some of the methods described in this document are not supported with unit cost and other operational information derived from full-scale field implementation. Moreover, the cost information (if available) of laboratory and pilot-scale model tests more than likely would not translate dollar-for-dollar to actual full-scale remediation efforts. Several of the treatment methods are still in the research stage; success in the laboratory or in pilot-scale tests may not reliably indicate the effectiveness of the method in the field.

1.2 Background

On March 19, 2008, the Site was placed on the National Priorities List (NPL), and on November 20, 2009, MIMC and IPC (the Respondents) received the UAO requiring that the Respondents conduct an RI/FS at the Site. In addition, MIMC and IPC entered into an Administrative Order on Consent (AOC), Docket No. 06-12-10, in May 2010 to perform a time critical removal action (TCRA). The activities of the TCRA are outlined in the *Removal Action Work Plan* (RAWP), prepared by Anchor QEA, LLC, (Anchor QEA) in November 2010, and revised in February 2011[1] and the *Draft Removal Action Completion Report* (September 2011).

[1] The revised RAWP was submitted to the USEPA on February 23, 2011, and approved by the USEPA on March 3, 2011.

The Site consists of a set of impoundments, 15.7-acres in size, built in the mid-1960s for disposal of paper mill wastes, and the surrounding areas containing sediments and soils potentially contaminated with the waste materials that had been disposed of in the impoundments. A set of impoundments is located on a partially submerged 20-acre parcel on the western bank of the San Jacinto River, in Harris County, Texas, immediately north of the Interstate Highway 10 (I-10) Bridge over the San Jacinto River (Figure 1-1).

USEPA has information that indicates that an additional impoundment is located south of I-10. This information indicates the additional impoundment contains material similar to that disposed of in the two impoundments north of I-10. USEPA has not identified any evidence of releases or threatened releases from the additional impoundment; however, new data for this area was generated as part of the RI/FS soil sampling and analysis plan addendum (Integral and Anchor QEA 2011) and are currently being evaluated.

A full description of the Site history is provided in the RI/FS Work Plan (Anchor QEA and Integral 2010).

The RI/FS will determine the need for further remedial action at the Site, following the implementation of the TCRA. In their approval of the RI/FS Work Plan (November 2, 2010), USEPA provides RI/FS "process direction" stating that the waste impoundments north of I-10 are source material, to be considered principal threat wastes. At that time, USEPA also directed Respondents to make a determination in the RI as to whether "the Site's contaminated materials" (i.e., sediment and soil outside of the northern impoundments) are principal threat wastes or low level threat wastes. According to USEPA guidance, source materials constituting principal threat wastes may be contained or treated as part of the final remedy, but that treatment must be considered (USEPA 1991).

1.3 TCRA Implementation

The TCRA was implemented to stabilize pulp waste and sediments within the original 1966 perimeter berm of the impoundments north of I-10 to prevent the release of dioxins and furans and other COPCs to the environment (Anchor QEA 2010).

1.3.1 TCRA Components

The area within the original 1966 perimeter was separated into three distinct areas: the Eastern Cell, the Western Cell, and the Northwestern Area (Figure 1-2). In general, the TCRA design included an armor rock cap placed atop a geotextile bedding layer. The one exception is that the Northwestern Area did not receive a geotextile bedding layer. Additionally, the Western Cell also received a geomembrane cover layer prior to armor rock installation.

Four different armor rock gradations were specified for the cap material. The armor cap layout is provided in Figure 1-2. Each of the armor rock types and minimum thicknesses is provided in Table 1-1, along with the final in-place quantities for each type.

Table 1-1

TCRA Armor Cap Rock Components

Material	Stone Size D_{50} (inch)	Minimum Thickness (inch)	Installed Quantity (ton)
Armor Cap A	3	12	13,500
Armor Cap B/C	6	12	11,300
Armor Cap C	6	12	10,100
Armor Cap D, D_{24}	8	18, 24	23,900
		Total:	58,800

Notes:
All quantities have been rounded to the nearest 100 tons.

Both land- and water-based equipment were used to complete the TCRA construction. Land-based construction equipment included long-reach excavators, dozers, and front-end loaders. Water-based construction operations occurred via barge. A long-reach excavator was mounted on a material placement barge and was used to install armor cap materials directly atop the deployed geotextile layer. The water-based geotextile as-built drawing is provided in Figure 1-3.

Prior to geotextile, geomembrane, and armor rock installation in the Western Cell, the low-lying areas were stabilized using an 8 percent by weight Portland cement admixture. A total of 430 tons of Portland cement was used to complete the stabilization. The surface was then graded and received three geosynthetic layers: 1) 12-ounce (oz) geotextile, 2) 40-millimeter linear low density polyethylene (LLDPE) geomembrane, and 3) 16-oz geotextile. The Western Cell geotextile and geomembrane as-built drawing is provided in Figure 1-4. The total quantities for geotextile and geomembrane installed during the TCRA are 79,000 square yards (sy) and 15,400 sy, respectively.

A full description of the TCRA implementation is provided in the Draft Removal Action Completion Report (RACR) (Anchor QEA 2011).

1.3.2 TCRA Site Treatment

In situ treatment of materials isolated by the armored cap could involve adding adsorptive media, such as activated carbon, to the armor cap to limit the potential transport of dissolved COPC. This treatment method may require placement of additional materials on top of the armored cap.

Ex situ treatment of the contaminated materials at the TCRA Site would require the removal of all installed TCRA stabilization components (i.e., geotextile, geomembrane, and armor rock material). It is anticipated that the means and methods necessary for the satisfactory deconstruction and removal of the TCRA armor cap would be similar to the construction methods described in the RACR (Anchor QEA 2011). Additionally, prior to off-site transport, the removed TCRA stabilization components may require temporary storage in lined containers or barges suitable for storing and transporting contaminated materials. During the course of removal operations, especially water-based, implementation of best management practices (BMPs) would be needed to prevent the resuspension and release of contaminated materials from the work area.

As discussed in Section 1.3.1, a portion of the Western Cell was stabilized prior to installing the armor cap. The stabilization was performed to reinforce the upper layers of soft soils, which allowed construction equipment to access the interior portion of the cell. The stabilization treatment also likely reduced the mobility of the contaminants by reducing the overall permeability of the materials; although testing was not performed to determine the degree of immobilization that was achieved.

If the TCRA armor cap and associated geotextile and geomembrane are removed from the Site, each would require proper disposal or treatment. As part of the removal operations, it would be necessary to establish an off-site facility for staging and decontamination areas to receive and process the armor rock. The staging and decontamination areas would be constructed to capture run-off generated by drainage and decontamination operations. Additionally, as a protective measure, containment berms lined with polyethylene sheeting could be used to contain rinseate spillage. The staging and decontamination facility would have adequate dock space for equipment to unload the armor rock, sufficient interior space to allow for equipment to manage segregated stockpiles before and after treatment, and a loading area for trucks transporting the material to off-site disposal.

Proper methods for decontaminating the armor rock are not presented in this evaluation. Depending on the facility's containment capabilities, high pressure washing or low pressure flushing may be appropriate methods for decontaminating armor stone. The run-off would require proper handling (e.g., vacuum trucks) and treatment. Following decontamination, the armor rock may be placed in an approved landfill for disposal if it could not be reused at the Site.

Depending on the method selected (i.e., in situ or ex situ), the contaminated material would either receive treatment on-site or be excavated for treatment at an approved off-site facility. Section 3 describes both types of treatment implementation methods.

2 SITE CHEMICALS OF POTENTIAL CONCERN

Appendix C of the RI/FS Work Plan (Anchor QEA and Integral 2010) describes the methods and rationale for the selection of Chemicals of Interest (COI) that are used as the basis for identification of COPCs for the RI/FS. The COIs were selected from the USEPA priority pollutants that meet the following criteria. To be selected as Site COIs, the chemicals were reported by one or more technical papers as potentially occurring in pulp mill solid wastes or leachate from solid waste landfills containing pulp mill wastes. Further, the chemicals would need to have chemical or physical properties, such as strongly partitioning to sediment organic carbon, which would make them likely to have persisted for more than 40 years in the Site environment. These COIs provided the starting list from which primary and secondary COPCs were identified.

Appendix C of the RI/FS Work Plan (Anchor QEA and Integral 2010) establishes the use of dioxins and furans as an indicator chemical group for the Site, a concept provided for USEPA guidance on performance of RI/FS at CERCLA sites (USEPA 1988). This designation was made because dioxins and furans are persistent, are likely the most toxic chemicals at the Site, and are likely to contribute most significantly to the overall risk at the Site. The use of dioxins and furans as indicator chemicals helps to focus the required analyses, reducing the time required to develop and evaluate remedial alternatives. Integral (2011) identifies additional Site COPCs:

- Metals
    - Aluminum
    - Arsenic
    - Barium
    - Cadmium
    - Chromium
    - Cobalt
    - Copper
    - Lead
    - Magnesium
    - Manganese
    - Mercury

    - Nickel
    - Thallium
    - Vanadium
    - Zinc
- **PCBs**
- **Semivolatile Organic Compounds**
    - Polychlorinated Biphenyls (PCBs)
    - Phenol
    - Carbazole
    - Bis(2-ethylhexyl)phthalate

Because dioxins and furans are designated as the indicator chemical group for the Site, this treatability study review is focused on treatment technologies for dioxins and furans in potentially contaminated soils and sediments. Many of the treatment technologies reviewed are also applicable to the semivolatile organic COPCs, and some are also applicable to treatment of the metal COPCs.

The physical and chemical properties of dioxins and furans are pertinent to the review of potential treatment technologies. Dioxins and furans are persistent in the environment. They adsorb strongly to soil and sediment, and they have low solubility in water, but the solubility may be increased significantly in the presence of high concentrations of other organic compounds (USEPA 1989). Table 2-1 provides some chemical properties for dioxins and furans; PCBs are included for comparison and further discussion in the Review of Treatment Methods section below.

Table 2-1

Chemical Properties of Dioxins, Furans, and PCBs (USEPA 2010)

Chemical	Water Solubility (mg/L)	Octanol/Water Partitioning Coefficient (Log K_{ow})	Organic Carbon Partitioning Coefficient (Log K_{oc})
PCB	0.42	5.60	>5,000†
2,3,7,8-TCDD	0.00193*	6.8*, 7.02-8.70	N/A (very low mobility in soil)
Furans	0.010	4.00-5.00	N/A (very low mobility in soil)

Notes:
*Values supplemented from the Technical Factsheet on: Dioxin (2,3,7,8-TCDD) (USEPA 2002a)
†Values supplemented from the Technical Factsheet on: Polychlorinated Biphenyls (PCBs) (USEPA 2002b)

3 REVIEW OF TREATMENT METHODS

This section presents a review of specific treatment technologies applicable for dioxins and dioxin-like compounds. The information provided represents an overview of potential treatments for paper mill wastes, contaminated sediment, and contaminated soil at the Site. Treatment technologies include those that reduce toxicity by destroying the dioxin molecule, and those that reduce the mobility and bioavailability of the dioxin by altering the physical or chemical properties of the affected material.

Each of the potentially available technologies was evaluated considering the likely long-term effectiveness, implementability, short-term effectiveness, and cost. This evaluation is similar to the screening evaluation of remedial alternatives described in 40 CFR 300.430 (e)(7) and will be applied to the development of remedial alternatives in the FS. Unlike the FS, however, the purpose of this evaluation is not to select a remedial alternative or to select treatment technologies. Rather, the purpose of this evaluation is to identify treatment technologies that may be applicable to one or more remedial alternatives at the Site and to assess whether treatability testing is needed prior to development of the FS, so that promising treatment technologies can be effectively included in the evaluation of remedial alternatives in the FS. The effectiveness evaluation for each technology considers a variety of factors, including: 1) the demonstrated performance of the technology, 2) the applicability of the treatment to the COPCs, 3) physical characteristics of the Site, and 4) the ability of the treatment method to efficiently remove or immobilize the COPCs. The implementability evaluation considers factors that include the operations and maintenance requirements. Each of the methods evaluated is subject to the implementability issues that would arise, should it be determined that treatment of the contaminated material within the TCRA Site is necessary. A description of the removal and decontamination of the TCRA stabilization components is provided in Section 1.3.2.

Where such information is available for an individual technology, the anticipated unit cost to treat contaminated materials is presented in this document. Current cost information for these treatment technologies was collected by contacting vendors and reviewing recently completed projects. A complete description of any remedial alternative, particularly one that includes ex situ treatment, such as incineration or chemical dehalogenation, will require many other components (e.g., dredging, decontamination, stabilization, and transportation) that will be described by the FS. An initial order of magnitude estimate is provided for several ex situ treatment options in Section 4 – Summary and Conclusions. The costs for these additional components are not intended to represent complete pricing for any of the remedial alternatives listed; rather, the intended use is solely as an order of magnitude comparison among technologies included in this document. Should an ex situ method be recommended for evaluation in the FS, further analysis of costs associated with that technology will be provided in the development of costs for the remedial alternatives.

Order of magnitude cost information is not provided for ex situ treatment of the contaminated materials stabilized by the TCRA. As described in Section 1.3.2, ex situ treatment would require the removal of all installed geotextile (79,000 sy), geomembrane (15,400 sy), and armor rock material (58,800 tons). The cost for removing the TCRA components may exceed the estimated construction cost ($8.78 million) reported in the RACR (Anchor QEA 2011). Should the contaminated material within the TCRA Site require treatment, a thorough assessment of the implementation costs and associated risks would be required.

The purpose of this evaluation is to identify technologies that may be appropriate for consideration in the development of remedial alternatives, and to assess whether sufficient information is available to evaluate remedial alternatives that include these technologies in the FS. The outcome of this evaluation is to identify each of the potential technologies as falling in one of the following categories:

- Inapplicable to the remedial action for the Site (no treatability testing).
- Potentially applicable to the remedial action with sufficient information available to evaluate in the FS (no treatability testing).
- Potentially applicable to the remedial action but requiring additional information to evaluate in the FS (treatability testing required).

3.1 Thermal Treatment

Thermal treatment technologies remove contaminants from soil and sediment by applying sufficient heat, with or without reduced pressure, to volatilize the contaminants. Once the contaminants are volatilized, they are chemically altered at high temperatures by oxidation (combustion) or pyrolysis (thermal decomposition without oxidation). There have been many applications of thermal treatment to contaminated waste sites, and advancements in the types of technologies have made the treatments safer and more effective. Two thermal technologies are reviewed in this document: incineration and thermal desorption.

3.1.1 Incineration

Incineration of environmental media or waste contaminated with dioxins requires high temperatures (greater than 1200°F) and relatively long residence times (30 to 90 minutes) (USEPA 1998). This method volatilizes the contaminants from the environmental matrix. The vapor containing air and organic contaminants reacts to form carbon dioxide and water vapor. Other contaminants are formed if oxidation is incomplete. Permits for incinerators strictly limit the allowable generation of products of incomplete combustion (PIC), and operating conditions (temperatures, residence times, contaminant inflow, and excess air flow) are carefully controlled to maximize the destruction of contaminants and minimize the generation of PICs. Based on the type of incinerator, multiple heating chambers may be necessary to achieve the residence time required to fully oxidize the contaminated material. The portion of the material that cannot be incinerated (fly ash) is removed from the system. As required by emissions permits, the off-gases are captured and treated by a scrubber system prior to release.

Both the ash material produced and the off-gas released from the incinerator system is scrutinized heavily for contaminant content. In order to be permitted, an incinerator facility must meet local, state, and federal requirements for emissions standards. This technology can be applied both on- and off-site; however, as will be discussed in Section 3.1.1.3, on-site incineration is not applicable for the Site.

An off-site incinerator is located at the Veolia Environmental Services (Veolia) facility[2] in Port Arthur, Texas, which is located approximately 72 miles from the Site. This facility is capable of treating wastes from the Site and has been used to treat some materials removed from the Site during the sampling for the RI/FS. A waste profile for the contaminated

[2] http://veoliaes-ts.com/Facilities/Port-Arthur-TX-information

material from the Site has already been compiled and approved for treatment at the Veolia facility. Veolia confirmed that the dioxin-contaminated soil and sediment can be incinerated at the facility, regardless of the concentration of dioxin. Soils and sediments would be delivered to the facility in roll-off boxes. Waste water generated by dewatering and decontamination activities can also be disposed of at this facility (Stringer 2011). Water with less than 5 percent solids can be transported via a vacuum tanker truck; sludge and water with greater than 5 percent solids can be transported in a vacuum box. Vacuum boxes require a processing time of 4 to 6 weeks; therefore, appropriate lead time is required when transporting waste using these containers.

3.1.1.1 Long-Term Effectiveness

Incineration is an ex situ treatment technology; therefore, removal of the source material from the Site is required prior to treatment. The risks associated with the contaminated sediment would be fully addressed by the removal of the sediment from the aquatic environment. As mentioned in Section 3.1.1, incineration is capable of removing dioxins from contaminated media and chemically altering the dioxin to harmless constituents. Incinerators operating in compliance with environmental permits have been shown to effectively and safely treat soil, sediment, and debris contaminated with dioxin and related compounds.

3.1.1.2 Short-Term Effectiveness

Incineration requires the removal of the contaminated source material prior to treatment. Dredging operations result in the resuspension of contaminated sediments into the water column. BMPs would be implemented to minimize the release of contaminated sediment from the work area. If dredging is selected as the remedial action in the navigation channel, coordination with commercial traffic would be required to mitigate the risks of collision with and/or contaminant release from the dredge, pipeline, and all other equipment incidental to sediment removal.

In addition to the upland treatment facility for dredged sediment, facilities would be required for unloading, dewatering (if required), and stockpiling sediment for transportation by truck or rail to the treatment facility. Transportation of the contaminated sediment to the treatment facility would require planning and coordination with public safety authorities to minimize hazards associated with traffic and the potential release of contaminated material.

Water drained from the sediment would need to be treated at the dewatering location prior to release, or collected in tanks for treatment at another facility. Secondary containment and BMPs would be required to prevent releases from these operations to the environment.

3.1.1.3 Implementability

Although on-site, transportable incinerators have been used at Superfund sites; the Site is an unsuitable location for ex situ treatment for several reasons. There is limited space at the Site, there are no berthing facilities or suitable locations for developing such facilities; the entire surface of the impoundments north of I-10 was recently capped; the Site is located within a floodplain; and there are residential areas adjacent to the Site. For the same reasons, the Site is unsuitable for offloading dredged sediment from barges or for staging materials. Additionally, on-site incineration must meet the requisite local, state, and federal air emissions regulations; however, the proximity of the Site to the adjacent residential areas would be prohibitive to establishing the necessary air quality permits for operation.

To implement incineration, dredged sediment would need to be transported by barge to a suitable offloading facility, where the sediment could be dewatered, and transferred to truck or rail for transportation to a commercial incinerator, such as the Veolia facility, for treatment. Implementation of any ex situ treatment would require establishing an agreement with an intermediary facility for unloading barges and loading the sediment into trucks or rail cars. The offloading facility would also be required to obtain and operate in compliance with applicable permits.

3.1.1.4 Cost

Treatment costs for incineration were obtained from the Veolia facility. The waste would be transported to the facility in roll-off boxes. The unit cost for incineration is $900 per ton, and the roll-off boxes must meet a minimum requirement of $5,000 per shipment (Stringer 2011). Treatment costs for water removed from the sediment were also obtained from Veolia. If the water contains less than 5 percent solids, it can be delivered in a vacuum tanker truck and the treatment cost is approximately $300 to $500 per ton (Stringer 2011). Water containing greater than 5 percent solids, along with sludge material, can be transported to the facility in a vacuum box, which would have a unit cost of $900 per ton (Stringer 2011). Additional costs for dredging, decontaminating, offloading, rehandling, and transport of the material are not included in this unit cost. Also, the cost for the establishment of an intermediary facility used for barge offloading and truck loading has not been included in the above unit costs.

3.1.1.5 Recommendations

Incineration has been proven to successfully destroy dioxins in contaminated media. Moreover, since investigation-derived waste from the Site has been treated by Veolia using incineration, treatability testing is not necessary for the FS. Further coordination and cost estimate development for the dredging, decontaminating, offloading, rehandling, and transport would be necessary to fully resolve the applicability of this method to the current Site conditions.

3.1.2 Thermal Desorption

The In Situ and In-Pile Thermal Desorption (ISTD and IPTD, respectively) technology uses a heated negative pressure environment to treat contaminated soils and sediments. A variant of the IPTD is the In-Barge Thermal Desorption (IBTD) (Baker et al. 2006), which could be applied to material at dockside locations; although, IBTD has not been applied to any of the researched demonstration- or field-scale tests presented below. Reduced pressure is used to lower the temperature at which contaminants desorb and volatilize from the affected soil or sediment. Thermal conduction heating is used to raise the temperature of the affected medium for residence times of up to several days—42 days for soil treatment at the Missouri Electric Works, a site with PCB and dioxin contamination (Stegemeier and Vinegar 2001). Most of the contaminants are destroyed in place by oxidation or pyrolysis; other volatilized contaminants are extracted and treated outside of the piles.

Dioxins begin to decompose at temperatures as low as 300°C to 400°C in a reduced-oxygen environment; therefore, a minimum temperature of 335°C is suggested for the treatment of dioxin contaminated soils and sediments. Dioxins are removed from the affected medium by oxidation, pyrolysis, and volatilization. Previous research indicates that thermal desorption is capable of removing 95 percent to 99 percent (or more) of the contaminant from the soil/sediment (Baker et al. 2006). The IPTD process has been proven to achieve a destruction and removal efficiency of >99.9999 percent for dioxin contaminated sites (Baker et al. 2009).

IPTD was evaluated as a treatment for the dioxin-contaminated soil and sediment from the site. Differences between IPTD and the other treatment method variants are noted in the following discussion. As indicated by the IPTD name, excavated material is placed in piles or "cells" for treatment. Each "cell" is constructed above ground with a foundation, containment berms, insulating walls and cover, and treatment wells. Three types of wells used for IS/IP/IBTD treatment: 1) heater wells, 2) heater-vacuum wells, and 3) air inlet (injection) wells.

The following description of well construction and placement is summarized from Stegemeier and Vinegar (2001). The heater and heater-vacuum wells are constructed similarly. These wells are usually constructed first by making 6-inch diameter holes with an exterior and interior annulus of sand. The exterior annulus of sand is contained around the well casing with a size 10 to 20 mesh. The interior annulus is contained with a 4-inch to 4.5-inch diameter stainless steel slotted (0.032-inch by 2-inch) mesh liner (size 40 mesh). A 2.5-inch diameter "heater can," which is sealed at the bottom, is installed in the interior annulus.

The air-gap between the "heater can" and the stainless steel slotted mesh liner is used in the vacuum wells to evacuate air upward from the contaminated medium. The "heater can" contains nichrome wires that are used as the heater elements. The wires are threaded through ceramic insulators and extend the length of the "heater can." The top of the well is fixed by capping with concrete.

Air inlet or injection wells are placed near each heater well. These wells are similar to the others, but do not contain heater elements. Air is injected into the soil or sediment next to the heater to oxidize the organic contaminants in the affected medium.

The spacing and placement of wells is subject to the design constraints presented by a particular project. Research suggests that the spacing between the wells should not exceed the total depth of contaminated soil/sediment. Wells are typically laid out in a hexagonal pattern, such that the heater-vacuum wells are located at the center of each hexagon. The wells may be oriented horizontally or vertically (Baker 2011a; Baker 2011b).

3.1.2.1 Long-Term Effectiveness

The IPTD treatment method is an ex situ technology; therefore, removal of the source material from the Site is required prior to treatment. The IPTD treatment is capable of destroying the dioxin present in the sediment. The treated sediment could be beneficially reused, unless there are additional contaminants that are resilient to thermal desorption, such as heavy metals (Baker 2011b). ISTD/IPTD has been successfully applied to four dioxin contaminated sites: Yamaguchi, Japan; Alhambra, California; Cape Girardeau, Missouri; and Ferndale, California. The Cape Girardeau, Missouri and Yamaguchi, Japan sites were demonstration-scale tests, while the remaining two were full-scale applications (Baker 2011a). The maximum average pre-treatment toxic equivalency (TEQ) concentration for these four sites was 18,000 pg-TEQ/g (Alhambra, California), which was reduced to an average concentration of 110 pg-TEQ/g (Baker 2011a). Treatment at this site achieved the target concentration levels, and post-treatment, the California Department of Toxic Substances Control issued a No Further Action letter and did not place any restrictions on the land usage (Baker et al. 2007; Baker 2011b).

3.1.2.2 Short-Term Effectiveness

As with all ex situ technologies, IPTD requires the removal of the contaminated source material prior to treatment. Risks of implementation associated with dredging contaminated sediment, managing the sediment in stockpiles, and transporting the sediment to a treatment facility are discussed in Section 3.1.1.2 and would be the same for thermal desorption.

3.1.2.3 Implementability

The Site is an unsuitable location for ex situ treatment, offloading dredged sediment from barges, or staging materials, as there is limited space, there are no berthing facilities or suitable locations for developing such facilities, the entire surface of the waste impoundments were recently capped, the Site is located within a floodplain, and there are residential areas adjacent to the Site.

Dredged sediment would need to be transported by barge to a suitable offloading facility where the sediment could be dewatered and transferred to truck or rail for transportation to a facility for ex situ treatment. Implementation of any ex situ treatment would require establishing an agreement with a facility for unloading barges and loading the sediment into trucks or rail cars.

Land would need to be acquired for the construction of the temporary treatment facility. Since the offloading and treatment facilities would be off-site, permits would be required for the construction and operation of these facilities. Several acres would be required to accommodate the treatment piles and ancillary operations, including stockpiles for untreated and treated soil, equipment storage, and off-gas treatment.

Site access and security are also considerations for any treatment effort. Cooperation from local and state agencies would be necessary to ensure that all parties concerned are aware of the requirements of the IPTD treatment method and that contractors and their sub-contractors, if applicable, can safely and adequately construct and manage the IPTD cells.

Based on the available information, the treatment time required for each batch of contaminated sediment can range from approximately 40 to 150 days; however, this treatment time is dependent on multiple factors, including the quantity and moisture content of the soil. While the IPTD method can handle a dredged slurry of contaminated sediments, the water content of the sediments will affect the time and energy required to heat the matrix (Baker 2011b). Therefore, it may be necessary to dewater the material prior to the IPTD treatment. The preferred dewatering agents are calcium carbonate or lime. Additionally, this time constraint must be considered in light of the excavation production rate, the staging area required for dewatering the material, if necessary, and the amount of treatment cells capable of fitting on the treatment Site.

3.1.2.4 Cost

Treatment costs are estimated based on information provided by TerraTherm. The estimated cost to treat dioxin-contaminated sediments is \$250 to \$500 per cubic yard (cy) (Baker 2011b). If a unit weight of 1.4 tons per cy were assumed for the material, then the unit cost range would be $350 to $520 per ton. These figures are a generalization and do not represent an actual quote for services. The unit cost provided is a "turnkey" cost, which includes design, equipment, and implementation; however, it does not include the requisite cost for sediment excavation and dewatering, if necessary. Additionally, the costs for land acquisition and transportation to and from the off-site treatment piles are not included in the turnkey unit cost range.

3.1.2.5 Recommendations

The IPTD treatment technology has been field-tested and can successfully remove and destroy dioxins from contaminated soil and sediment matrices. As with any of the ex situ treatment technologies, a significant challenge will be identifying suitable locations for and acquiring the necessary permits for transloading sediment from barges to overland transportation and for the treatment facility. TerraTherm, a vendor that provides IPTD treatment, recommends performing site-specific testing on the material prior to selecting the IPTD method for treatment. This technology is viable for treating the sediment from the Site; although, it is subject to implementability challenges that would apply to all ex situ treatment technologies that would require temporary facilities, as discussed in Section 3.1.2.3. Previous experience, including full-scale demonstrations, indicates that the technology would effectively remove dioxin from the sediment. Therefore, treatability testing would not be necessary to evaluate this technology in the FS. If a remedial alternative is selected that includes IPTD, site-specific treatability testing would be needed as part of remedial design to determine the affect of sediment moisture content on the treatment time, which would affect the dimensions of the treatment cells and the cost of treatment.

3.2 Chemical Degradation

3.2.1 Dehalogenation

Dehalogenation treatments use chemical and thermal processes to break down dioxins in contaminated soil and sediment. Treatment is achieved either through the removal of chlorine (a halogen) atoms from the dioxin molecules or through decomposition or volatilization of the contaminants (FRTR 2008). All of these technologies are applied to the contaminated media ex situ and require pre- and post-treatment to complete the process (e.g., dewatering, thermal desorption, debris removal, and/or reagent removal). Several methods have been applied as field-scale treatment operations and are described below.

The modified Alkaline/Potassium Polyethylene Glycolate (APEG/KPEG) method, APEG-PLUS, was developed by Galson Remediation Corporation, in the late 1980s. The technology uses a mobile treatment facility paired with a modified reagent, which uses potassium hydroxide and dimethyl sulfoxide to remediate contaminated soils and sediments. As outlined by the Office of Technology Assessment (OTA), this process takes a contaminated matrix, along with the APEG-PLUS reagents, and forms a slurry, which separates the chlorinated contaminants. The slurry is added to a reactor that heats the mixture and causes the polyethylene glycolate molecule to replace the chlorine atoms in a chlorinated dioxin molecule to form glycol ether, which can be readily broken down by the natural environment (U.S. Congress 1991). Reagents are separated from the soil matrix mixture by centrifuge; the soil is washed and the effluent is treated with activated carbon. Recent applications and vendors of this technology were not found while researching for this document; therefore, none of the polyethylene glycolate technologies will be evaluated any further.

The Solvated Electron Technology™ (SET) is a full-scale, ex situ chemical dehalogenation treatment process. The process involves mixing the contaminated soil or sediment with a solvated electron solution (alkali metal or alkaline earth metal mixed in liquid anhydrous ammonia) in a treatment vessel. Chlorine is removed from the chlorinated organic molecules, leaving the parent contaminant molecule (nonchlorinated dioxin in this case) and metal salts, such as sodium chloride. The vessel is then heated using hot water or steam to remove the ammonia for reuse. SET has been used to treat dioxin-contaminated sludge and oil from the New Bedford Harbor Sawyer Street site in Massachusetts and the McCormick and Baxter site in Stockton, California (Vijgen 2002b). The technology's patent holder, developer, and vendor is Commodore Advanced Sciences, Inc., and according to their website[3], five other sites with PCB contamination have been successfully treated. Only one of these sites, the Pennsylvania Air National Guard Site in Harrisburg, is listed by the USEPA (2010) as a full-scale application of SET for PCBs.

[3] http://www.commodore.com

Base-Catalyzed Decomposition (BCD) is another full-scale, ex situ technology that has been successfully applied in the U.S. and countries around the world. The patent holder of this technology in the U.S. is the USEPA. According to the USEPA (2010), this treatment technology requires pre-treatment via thermal desorption to remove the contaminants from the soil/sediment matrix by volatilization. The volatilized contaminants pass through a condenser and are fed into a liquid tank reactor, along with sodium hydroxide and a carrier oil. The mixture is then heated for 3 to 6 hours to temperatures above 326°C. The oil is tested post-treatment and the carbonaceous residues formed from the reaction are removed from the mixture; the carrier oil can then be reused for subsequent treatment applications (Vijgen 2002a; Vijgen and McDowall 2009[4]). The soil and sediment treated via thermal desorption can be reused as fill material. Vijgen (2002a; Vijgen and McDowall 2009) report that a full-scale application of this technology was conducted in 1997 in Binghamton, New York and treated 2,500 tons of dioxin contaminated waste. The most recent application of the BCD technology was in the Czech Republic, which began with treatment testing in 2003 to 2004; full-scale operations began in 2006.

3.2.1.1 Long-Term Effectiveness

The chemical dehalogenation treatment methods are ex situ technologies; therefore, removal of the source material from the Site is required prior to treatment. The risks associated with the contaminated sediment would be fully addressed by the removal of the sediment from the aquatic environment. Research indicates that dehalogenation is capable of reducing the concentration of dioxin in contaminated soil and sediment. Following treatment, the soil and sediment would likely require landfilling for ultimate disposal, which would limit the exposure point of ecological receptors to residual concentrations; thus the material would have a negligible long-term impact to the environment.

3.2.1.2 Short-Term Effectiveness

As with all ex situ technologies, chemical dehalogenation requires the removal of the contaminated source material prior to treatment. As outlined in Section 3.1.2.2,

[4] Vijgen and McDowall (2009) prepared an update to the existing 2002 fact sheet for BCD. The website source (www.ihpa.info) indicates, however, that this resource has not been peer-reviewed. As necessary, both resources are cited for completeness.

considerations for dredging at the Site include the resuspension and movement of source material; the interference with navigation channel traffic; and the establishment and maintenance of an off-site unloading, dewatering, and stockpiling facility.

The equipment necessary for the chemical dehalogenation treatment would need to be deployed at an off-site location because of restrictions on the use of the Site and the location of the Site in a floodplain; therefore, ex situ treatment on-site will not be discussed further. Transportation of the contaminated sediment to the established off-site treatment location would require planning and coordination with public safety authorities to minimize hazards associated with traffic and the potential release of contaminated material.

3.2.1.3 Implementability

As outlined in Section 3.1.2.3, the Site is located in a floodplain and is an unsuitable location for all stages of a removal and treatment effort, as the necessary facilities (i.e., berthing and staging/stockpiling) are not available; moreover, no suitable location is available for the establishment of such facilities. Additionally, a permitted off-site facility would be necessary to receive and dewater dredged sediments and allow for material transfer to truck or rail for transport to the temporary treatment facility. Land and the requisite permits would need to be acquired for the construction and operation of a treatment facility. Several acres would be required to accommodate the treatment equipment and ancillary operations, including stockpiles for untreated and treated soil, equipment storage, and off-gas treatment.

Site access and security are also considerations for any treatment effort. Cooperation from local and state agencies would be necessary to ensure that all parties concerned are aware of the requirements of the treatment method and those contractors and their sub-contractors, if applicable, can safely and adequately construct and manage the treatment equipment.

Based on the available information, neither treatment technology appears to be currently available in the U.S. According to Vijgen (2002a), the two technology providers responsible for previous applications of BCD to sites in the U.S. are no longer providing this treatment technology, and subsequent communication with the license distributor, BCD Group, Inc., indicates that no company is currently licensed to perform BCD treatment in the U.S.

(Opperman 2011). Additionally, no full-scale applications of the SET method for dioxin-contaminated waste are listed by either the USEPA (2010) or Vijgen (2002b).

3.2.1.4 Cost

As reported by Vijgen and McDowall (2009), current cost information for treatment at the facility in the Czech Republic is based on data from 2004; the reported unit cost range is €1,400 to €1,700 per ton. Assuming a 2004 conversion rate of $1.22[5] per euro, the unit cost range becomes $1,708 to $2,074 per ton. With the establishment of a permanent facility, the anticipated cost information for the treatment is €850 to €1,000 per ton. Again, assuming a 2004 conversion rate of $1.22 per euro the unit cost becomes $1,037 to $1,220 per ton. There is no cost information available in the research for the SET application to dioxin-contaminated wastes.

3.2.1.5 Recommendations

Chemical dehalogenation processes have been proven through field- and/or bench-scale testing to reduce dioxin concentrations to acceptable levels; therefore, no testing for these methods is required for the purposes of the FS. As with any of the ex situ treatment technologies, a significant challenge will be identifying suitable locations for and acquiring the necessary permits for transloading sediment from barges to overland transportation and for the treatment facility. This technology is viable for treating the sediment from the Site, although it is subject to implementability challenges that would apply to all ex situ treatment technologies that would require temporary facilities, as discussed in Sections 3.1.2.3 and 3.2.1.3. Treating the sediment with chemical dehalogenation would also cost considerably more than equally effective and more readily available methods. Additionally, vendors for chemical dehalogenation methods must be established prior to the selection of a chemical dehalogenation method. If a remedial alternative is selected that includes chemical dehalogenation, site-specific treatability testing would be needed as part of the remedial design to determine the reagent quantities necessary to reduce the dioxin concentration to an acceptable level.

[5] http://www.oanda.com/currency/converter/

3.2.2 Photolysis

Specific details regarding the affects of ultraviolet (UV) light on contaminated soil are summarized by Euro Chlor (2003). UV degradation breaks down contaminants through photolysis. Photolysis has been shown to be an effective method to transform dioxins in the upper layers of soil that can be penetrated by light. The transformation that typically occurs for dioxins is the dechlorination of the 1, 4, 6, and 9 positions, which is called peri-dechlorination (Euro Chlor 2003). The methods cited by Euro Chlor are all experimental and do not represent full-scale applications in the field. A limitation of this method results from the inability of sunlight to penetrate soil to a significant depth. Additionally, UV degradation requires a significant amount of space for the treatment. Information regarding the degradation rate of dioxins subjected to UV light has not been established for field-scale applications of this technology. Additionally, several studies presented by Euro Chlor indicate that the dechlorination of octachlorodibenzo-p-dioxin by photolysis would yield 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), which would increase the toxicity of the contamination. Based on the lack of field-scale applications and supporting data, along with the space limitations at the Site, this method is not recommended for further evaluation in the FS.

3.3 Biological Treatment

Bioremediation methods include those technologies that use microbes to metabolize contaminants present in the soil, sediments, and groundwater. These organisms require specific conditions for survival (for example, aerobic organisms require oxygen to survive and metabolize contaminants, whereas anaerobic organisms would be inhibited or poisoned by the presence of air). Under the wrong conditions, microbes could produce unwanted chemical by-products, reduce production, or die off. Bioremediation technologies are mostly in the research and development phase.

The dehalogenation capability of specific bacterial groups has been a long-standing research topic. Hieke (2008) presents a research effort that classifies a specific group of bacteria capable of dechlorinating dioxins: *Dehalococcoides*. These bacteria are anaerobes, indigenous to groundwater and freshwater systems, and are capable of dechlorinating various compounds. The products of dechlorination include less recalcitrant congeners of the parent chlorinated molecules, which can be metabolized by other microorganisms. The Houston Ship Channel and surrounding waterways down to Galveston Bay were classified as the study area in the Hieke (2008) research. All of the sediment samples taken from the area were anoxic, thus providing suitable conditions for *Dehalococcoides* to survive. Of all the samples analyzed, there was an apparent trend for a minimum TEQ concentration of approximately 3 ng/kg dry weight necessary for the *Dehalococcoides* bacteria to be present, and the range of concentrations of dioxin TEQ in sediment providing the first detection of *Dehalococcoides* is from 2.98 to 30 ng/kg dry weight. Additionally, the age of the sediment samples indicated that there was an "establishment period" of approximately 2 years necessary for *Dehalococcoides* to appear. The overall age range for the sediment samples where *Dehalococcoides* made their first appearance is 2 to 7.12 years. Hieke (2008) indicates that this time frame be accounted for in future studies that plan to consider *Dehalococcoides* as a remediation option.

3.3.1 Long-Term Effectiveness

The research presented by Hieke (2008) and Brinkmeyer et al. (2010) demonstrates that *Dehalococcoides* is a naturally occurring bacterial group in the Houston Ship Channel and surrounding waters; therefore, it can be assumed that removal of dioxin from the source material via these organisms has already begun to occur. In situ biological treatment may effectively reduce dioxin concentrations in the long-term. However, the process of dehalogenation by native bacteria may be very slow, as is suggested by the continued presence of elevated TEQ concentrations decades after the waste materials were placed at the Site. In addition, the treatment by these organisms would seem to be limited to reducing the dioxin concentrations to approximately 3 ng/kg dry weight.

Ex situ treatment would, as stated for previous methods, eliminate the presence of the source material in the channel and surrounding waters through dredging. The research suggests that treatment of dredged sediment by *Dehalococcoides* would be unsuccessful. The dredging and subsequent handling of the sediment would introduce oxygen that would need to be eliminated before a colony of *Dehalococcoides* could be established. Anoxic conditions would need to be maintained for the duration of the treatment period, which would be impractical considering the volume of sediment and the time required to achieve acceptable TEQ concentrations.

3.3.2 Short-Term Effectiveness

As noted in the previous section, the time required for *Dehalococcoides* to significantly reduce dioxin concentrations is considerably longer than the time that would be required for the other technologies reviewed in this evaluation. While the timeframe for in situ biological treatment may be reduced by adjusting conditions (such as adding nutrients or co-metabolites), additional research would be required to identify adjustments that would be effective and practical and to determine the degree to which such adjustments may accelerate the process and improve the final outcome.

3.3.3 Implementability

As discussed in the preceding sections, in situ biological treatment would be ineffective without some amendment of the sediment that would accelerate the process of dehalogenation. If research identifies amendments that would be effective and would not harm the environment, equipment is available for injecting reagents into the sediment or mixing reagents into the sediment. Agency approvals would be required for adding materials to the sediment.

3.3.4 Cost

Since this effort is a research-based initiative only, there is no unit cost information available for bioremediation using *Dehalococcoides*.

3.3.5 Recommendations

While Hieke (2008) presents a validation of the presence and activity of a bacterial species capable of dechlorinating dioxins, the evaluation of this technology indicates that it would not be suitable for remedial action. The treatment may not reduce concentrations of dioxin to acceptable levels, and even if the technology were effective in the long-term, the treatment period to achieve remedial goals may be much greater than the time to achieve protection by other remedial technologies. Therefore, this technology is not suitable for remedial action and will not require site-specific treatability testing.

3.4 Adsorbent Technologies

Adsorbent technologies have been applied to sites contaminated with persistent organic pollutants to reduce their presence in the surface water, thereby decreasing the likelihood for bioaccumulation. As discussed in this section, adsorbent technologies are applicable to sites with submerged contaminated sediments and may be added directly to contaminated sediment or as a component of a sediment cap. As discussed in Section 2, 2,3,7,8-TCDD has low solubility in water and partitions strongly to organic carbon. These characteristics make dioxins particularly amenable to treatment with adsorbents.

Two adsorptive materials, organoclay and activated carbon (AC), have been well-demonstrated for removing organic compounds from water. Both materials have been effectively used as amendments to contaminated soil and sediment or as amendments to granular caps. The mechanism by which each of these amendments removes contaminants from water differs. Because the active adsorption sites are on the surface of AC and the activation process creates very large active surface areas on micropores in a unit mass or volume of the material, AC is particularly well suited to removing trace amounts of contaminants from water (125 acres of active surface per pound of AC[6]). AC is susceptible to fouling in mixtures of water and oil because the oil can coat granules or particles of AC, blocking the entrances of the micropores, rendering much of the surface area unavailable for the adsorption of contaminants. For this reason, AC is poorly suited to removing organic contaminants from water if an oil phase is present, as the oil coats, or fouls, the AC rendering it ineffective. Organoclay is produced from bentonite clay modified with quaternary amines. The nitrogen in the amine reacts with the clay mineral, and the organic ends of the amine molecules attract organic contaminants. Organoclay is less subject to fouling than AC in the presence of nonaqueous-phase liquids.

The majority of studies found while researching previous adsorbent amendment testing for the Site have used PCBs as the target contaminant. From the chemical characteristics listed

[6] http://www.calgoncarbon.com/carbon_products/faqs.html

in Table 2-1, PCBs serve as a conservative surrogate for dioxins in evaluating literature data. Compared to PCBs, dioxins have lower solubility and higher partitioning capability; therefore, adsorptive materials should be more effective at reducing concentrations of dioxins as compared to PCBs. Based on observed PCB reduction, some (Ghosh et al. 2004) have estimated the percent reduction in aqueous concentration of dioxins (2,3,7,8-TCDD specifically) to be approximately 85 percent in the presence of an AC adsorbent amendment; additionally, the reduction of 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF) is estimated to be 95 percent. Moreover, a study by Goeyens et al. (2003) showed the ability of AC to adsorb a greater amount of dioxins than PCBs in contaminated dietary supplements consisting of marine oils. These studies indicate that AC is effective at removing PCBs from water and that AC may be at least as effective in removing dioxins from water.

Luthy et al. (2009) were responsible for field-testing the effects of AC when added to soils in situ. The study sought to affirm the validity of the AC treatment method and provide a field-scale test to assess the efficacy of this technology. The site chosen for the study was Hunters Point Shipyard in San Francisco, California, which was utilized from 1945 to 1974 by the U.S. Navy for ship maintenance and repair. For this remediation effort, AC was added to the upper 1 foot of sediments using two methods:

1. Mixing and tilling using Aquamog with rotovator attachment from Aquatic Environments, Inc.
2. Slurry injection using Compass Environmental, Inc. patented technology.

The tests proved that an AC amendment to PCB-contaminated soils would reduce the bioaccumulation of PCBs in a target species (bent-nosed clam; *Macoma nasuta*), reduce the PCB pore water concentration, and reduce the PCB-sediment desorption rate. The bioaccumulation was seen to decrease 30 to 50 percent in the target species, and the pore water concentrations were reduced 50 to 70 percent as a result of the AC amendment. In the laboratory setting, under more frequent mixing of the contaminated sediment with the AC amendment, samples displayed reductions of PCB partitioning greater than 95 percent.

Testing information for the performance of AC and organoclay to remove PCBs, specifically Aroclor 1260, from water is provided by Alther (2004). It should be noted that the Aroclor 1260 used in the experiment had a water solubility of 0.0027 mg/L. This value is similar to the dioxin solubility (0.00193 mg/L) provided in Table 2-1; therefore, on this basis, the Aroclor 1260 used in these tests is an adequate surrogate for dioxin. Mini-column tests with spiked water samples were performed for three types of adsorbent amendments: organoclay blended with anthracite (70 percent and 30 percent, respectively), organoclay, and Bituminous AC. Results are presented as the sorbent loading at breakthrough (mg/g) for each amendment and indicate that both materials are capable of immobilizing Aroclor 1260 in water.

Manufacturers of the amendment materials provided lab results and technical data sheets for their products. This information provides clarity to the ability and applicability of a certain material to a given design. Colloid Environmental Technologies Company (CETCO) produces and tests various types of organoclay material used for the treatment of contaminated sediments. A laboratory experiment performed with their PM 199, 100 percent organoclay adsorptive material compared its removal capability for pentachlorophenol and dioxin (CETCO 2007). An isodrin stock solution of 12.4 parts per million (ppm) was used as a dioxin analog for the experiment. The results indicate that the organoclay is capable of removing dioxins from water. Communications with the vendor (Bullock 2011a) indicate that site-specific testing is warranted to establish actual values for removal efficiency.

In addition to the bulk product described above, CETCO manufactures a Reactive Core Mat® (RCM), which is a remediation product constructed of two exterior geotextile layers and an interior "reactive core" material layer. Reactive materials from CETCO include organoclay and AC. Active material in the RCMs is given as a mass of reactive material per square foot (sf) of mat. The RCM specifications listed on the CETCO website indicate that the organoclay and AC mats have 0.8 pounds per sf and 0.4 pounds per SF, respectively, of active material. RCMs are manufactured in rolls measuring 15 feet wide by 100 feet long. Implementability and unit cost information provided by CETCO is discussed in the following sections.

AquaBlok is another manufacturer of remediation and treatment technologies. Their organoclay and AC products are coated on the exterior of aggregate materials. This type of manufactured product allows for flexibility of design, as the amount of bulk material can be varied on the exterior of the aggregate. By coating the aggregate with the adsorbent material, placement of the material becomes more precise than with bulk materials, as dispersal and amendment layer thickness are less controllable without the added weight of the aggregate. AquaBlok was consulted to assess the implementability of this technology and for the unit cost information provided in Table 3-1.

3.4.1 Long-Term Effectiveness

Organoclay and AC have both been demonstrated to be very effective and reliable for passively removing organic contaminants from water. AC is particularly effective for removing trace amounts of organic compounds from water; however, it is susceptible to fouling if exposed to high concentrations of organic contaminants, such as water mixed with nonaqueous-phase liquids. Organoclay is very effective for removing nonaqueous-phase liquids from water and is also effective for dissolved contaminants; although, it may be less effective than AC for removing already very low concentrations of organic contaminants from water (Reible et al. 2008). Dioxins have very low solubility in the water and partition strongly to the sediment. Therefore, AC may be a more suitable adsorptive material for the Site, given the need to reduce already low concentrations of dioxin in water passing from the sediment into the River. Other forms of organic carbon, such as agricultural byproducts, have also been added to contaminated sediment or cap material to increase the adsorptive capacity of the sediment or cap and reduce the concentration of organic contaminants in water. Such amendments may offer a more cost-effective alternative treatment, although the efficacy of such amendments would need to be demonstrated prior to their full-scale use.

The effectiveness of any adsorptive material relies on its ability to remain in place. Erosion of the adsorbent from any portion of the contaminated sediment area could cause resuspension of dioxin-contaminated materials into the surface water. The waters surrounding the Site are tidal and are prone to the daily fluctuation in stage and velocity; therefore, necessary means should be taken to ensure that the amendment material does not succumb to erosion. The FS will include an assessment of the need for an armor layer or cap to provide adequate protection against erosion of contaminated sediment and any adsorptive material. Also, any planned adjustments to the profile of the River bed would require further study to demonstrate that flood stage and navigation are not adversely affected.

3.4.2 Short-Term Effectiveness

The use of adsorbent technologies does not involve any particular hazards of implementation. Direct injection and shallow mixing techniques are available that minimize the resuspension of contaminated sediment. Amended cap materials may also be placed with minimal resuspension of contaminated sediment. The adsorptive materials would immediately begin removing dissolved contaminants from pore water that could migrate into the River through the sediment or a sediment cap.

Placement of materials, including adsorbent amendments, in the navigation channel, if required, would necessitate a coordinated effort between the contractor(s) and the vessel traffic anticipated along the River. As with the dredging operations described above for the ex situ treatment technologies, placement of the adsorptive material should be planned so as not to interfere with the navigation channel. Accurate placement is also a necessity; therefore, monitoring the flow in the channel and surrounding waters will be essential. Additionally, the RCM deployment should incorporate adequate overlap between panels. In the case of an adsorbent amendment, the material should be well-mixed with contaminated sediment or cap materials, and at application rates determined based on contaminant discharge rates and measured adsorptive kinetics.

3.4.3 Implementability

Adsorbent amendments are available from several vendors, and a variety of placement techniques are also available. Since the adsorbent amendments are applied in situ, the majority of the work will be water-side. Amendments could be added to affected sediment directly from barges. Amended cap materials would be blended prior to loading on barges and then placed mechanically or as a slurry. Luthy et al. (2009) describes that mixing or injecting an amendment material can achieve desirable reduction in contaminant concentration. Further evaluation of injection or direct mixing of amendments would be necessary prior to implementing this method for application at the Site.

AquaBlok materials can be placed with a stone-slinger telescopic articulated conveyor mechanism. Stone-slingers can be remote controlled and can spread aggregate or amendment material quickly over large areas; additionally, this equipment can operate land-side or water-side depending on the placement application requirements. An excavator mounted on a barge can be used to distribute the material. Layers as thin as 6 inches can be achieved by both methods (AquaBlok 2011). Additionally, from the AquaBlok website[7], other placement methods are available: crane and clamshell bucket or bulk bag (funneled bag attached to excavator bucket). Since the AquaBlok material is coated on the exterior of the aggregate, adsorbent amendment layers can conform to irregular surfaces. Placing this type of material also reduces the susceptibility of the reactive cap to scour, in certain applications, without the need for an additional erosion-protection layer (Collins 2011). Additionally, depending on the remedial design criteria, the percent of the reactive material coated on the aggregate can be varied to increase treatment residence time (Collins 2011).

In addition to successful applications at dewatered contaminated sediment sites, RCMs can be deployed to sequester subaqueous contaminated sediments. Previous application methods have used the RCM in conjunction with a sand cap layer. According to CETCO, deployment of an RCM with an AC core in an aqueous environment may require a sand cap layer to act as a weight to prevent the mat from migrating during and after placement; RCMs with an organoclay core are heavier and can typically be deployed with better consistency (Bullock 2011b).

As described in Section 1.3.2, the TCRA included capping contaminated sediment in situ to sequester contaminated material. Should the capped material require treatment, an adsorbent technology can be applied in situ. The presence of the TCRA cap materials (geomembrane, geotextile, and armor rock) would preclude tilling adsorbent materials directly into the affected sediment. Direct injection of adsorbents without removing the TCRA cap may not be possible, as the equipment may not be capable of penetrating the armor cap layers. Direct injection of adsorbents through the TCRA cap may not be desirable, even if it is possible, as injecting adsorbents into the sediment would require breaching the TCRA cap, potentially releasing contaminated sediment into the surface water. A potential alternative method to implement in situ treatment with adsorbent materials is to blend bulk adsorbent amendment material with sand and install an augmented cap layer atop the TCRA cap. The placement of an adsorptive layer on top of the TCRA cap may require the

[7] http://www.aquablokinfo.com

installation of additional cap rock to protect the adsorptive material from erosion. This type of cap enhancement would require consideration of the potential effects of the action on floodplain elevations, per Harris County Flood Control guidance. The other adsorbent technologies presented in this section, AquaBlok and RCMs, can be installed directly atop the TCRA stabilization components and are limited by the implementability issues described above.

As discussed above, placement location is a key component to the level of success of this treatment method. Advanced global positioning systems can provide real-time location information to operators to ensure that total coverage of the contaminated areas is achieved. It is suggested that such equipment be evaluated prior to contractor selection.

The land-side work would include the coordination of the material delivery, stockpile, and loading areas. Staging areas for all the material and equipment would be essential for this method. The property owned by LaBarge Realty, LLC, which has a dock and stockpile area upstream of the Site, was used to stockpile and load capping materials for the TCRA. This facility may be appropriate for similar operations in a full-scale remedial action.

3.4.4 Cost

Communications with AquaBlok and CETCO provided these general estimates for the costs of the adsorbent materials. An organoclay-coated aggregate material with 30 percent active material by weight would range from $1,000 to $1,500 per ton (Collins 2011). Similarly, an activated carbon coated aggregate material with 5 percent active material by weight would cost $400 to $450 per ton (Collins 2011). Raw organoclay and AC material are similarly priced at $1.25 to $1.65 per pound (Bullock 2011c; Collins 2011). The RCMs with organoclay or AC core material are estimated to be $2.40 per sf and $3.00 per sf, respectively (Bullock 2011b).

Hypothetical remedial action scenarios were developed to provide a common basis for comparing the costs of the different methods identified above. In this assessment, summarized in Table 3-1, the costs are compared on the basis of cost per unit area.

Installation cost is not considered. The assumptions that were made in order to make these comparisons are as follows:

- AquaBlok Application
  - Organoclay and AC materials both have a bulk density of 85 pounds per cubic foot (CF) (Collins 2011).
  - Both materials are assumed to be placed with a minimum thickness of 6 inches.
- Amendment Using Raw Materials
  - Organoclay and AC have average bulk densities of 50 pounds per CF[8] and 32.5 pounds per CF[9], respectively.
  - Amendment layers for both materials are 12 inches thick.
  - Application ranges from 3 percent by weight to 6 percent by weight.
  - Unit costs for both the AC and organoclay range from $1.25 to $1.65 per pound (Bullock 2011c; Collins 2011).
  - A 1.5-foot thick amended sand cap layer is applied to the TCRA Site.
- RCM Application
  - A 1-foot thick sand cap layer is applied to AC core mat.

[8] http://www.cetco.com/RTG/technicaldatasheets/Organoclay.pdf
[9] http://www.calgoncarbon.com/carbon_products/faqs.html

Table 3-1

Areal Cost of Adsorbent Technologies

Adsorbent Technology	Material	Areal Cost ($ thousands/acre)
AquaBlok	AC	$370 to $420
	Organoclay	$930 to $1,400
Amended Cap	AC	$170 to $450
	Organoclay	$170 to $450
Amended Cap TCRA Site	AC	$220 to $510
	Organoclay	$220 to $510
Reactive Core Mat (RCM)	AC	$160 to $190
	Organoclay	$110 to $130

Complete assessments of the contaminated material location, quantity, and physical properties should be used to establish treatment unit costs that are more representative of the conditions at the Site. Additionally, none of the above costs include the delivery, management, and installation of the material. The cost for the stockpile, offloading, and loading facility are also not included. Should an armor or sand cap be necessary to prevent erosion of the adsorptive material, appropriate material, and placement costs should also be considered.

3.4.5 Recommendations

Adsorbents merit further evaluation in the FS as a potentially applicable technology for the remedial action at the Site. Based upon the research and performance data presented for dioxins and PCBs, site-specific treatability testing for the FS is not necessary to determine the effectiveness of the adsorptive materials. Upon selection as a remedial alternative, site-specific testing would be appropriate to assess specific design parameters of each material (e.g., removal capacity and efficiency).

Other materials that would add organic carbon to the sediment or to a cap material may also be effective and should not be excluded from consideration. One approach that would foster innovation would be to demonstrate the effectiveness of materials, such as AC and organoclay, and set performance standards for remedial construction. Contractors would be invited to submit a proposal using one of the pretested materials with the option of proposing alternative materials. The alternative material could be shown to be more cost-effective if it is able to achieve the performance standard. If an adsorptive amendment technology is chosen for the remedial action, further modeling and coordination with suppliers would be necessary as part of remedial design to determine the thickness of the amendment layer and verify the necessity of an armor or sand cap atop the amended sediment.

3.5 Solidification/Stabilization

Solidification/stabilization (S/S) is a category of treatment technologies that involves blending the affected medium, such as contaminated soil or sediment, with a material that binds it into a solid matrix, increasing the strength and reducing the permeability and mobility of the material. Contaminants are encapsulated in the solidified sediment, meaning that the mobility of the contaminants is controlled both by reducing the potential for the sediment to be resuspended and reducing the flow of water through the sediment (permeability), thereby reducing advective transport of contaminants. Stabilization refers to treatment whereby contaminants, typically metals and more polar nonmetals, are also chemically bound to the solidified matrix (USEPA 2006). A variety of binders are available for S/S; although, the most common are pozzolanic reagents (e.g., Portland cement, fly ash, cement kiln dust), which are materials that react with lime in the presence of water to form rock-like solids.

S/S can be performed in situ or following dredging or excavation. In situ S/S may be accomplished using conventional excavators or specialized tillers or augers. Conventional excavators were used to stabilize approximately 5,500 cy of soft materials in the Western waste impoundment at the Site, to provide a stable surface for geomembrane and cap installation during the TCRA. Although sufficient water is essential for pozzolanic reactions, excess water can impede curing and result in a weaker final product. Proper mix ratios and equipment have been successfully used to solidify subaqueous sediment. The New Jersey Department of Transportation (Maher et al. 2005) successfully demonstrated the use of a deep soil mixer, a specialized auger, for solidifying subaqueous sediment containing a variety of contaminants including dioxin.

3.5.1 Long-Term Effectiveness

S/S is a well-demonstrated technology that has been used for numerous Superfund remedial actions (USEPA 2000b). The treatment binds fine sediment grains into a solid material that resists resuspension by erosive forces. The permeability of treated sediment is reduced and contaminants are encapsulated in the solid matrix, further reducing the mobility and bioavailability of the contaminants. S/S has been used for remedial actions for more than 20 years and various forms of concrete have been used in construction for many more years, so the reliability of the treatment is expected to be very high. Over many years, chloride ions in brackish water will diffuse into concrete and weaken the solid matrix. Unlike structural concrete, however, the shear strength of solidified sediment is not critical to its performance. Assuming that chloride attack weakens the solidified sediment, the material may crack and break down into pieces that are erodible over many years, but the mobility of the contaminants will still be controlled, such that the release is negligible.

3.5.2 Short-Term Effectiveness

The implementation timeframe for S/S is among the shortest of the treatment technologies. After removing standing water, sediments may be treated in situ using a conventional excavator bucket to a depth of 10 feet or more, with treatment rates of greater than 400 cy per day. The stabilization performed for the TCRA was limited to the first 3 to 5 feet below grade, and the treatment rates were approximately 900 cy per day or greater. Specialized equipment, such as soil-mixing augers, can treat subaqueous sediment to greater depths, if necessary; the actual mixing time for a 10-foot-deep treatment was 10 minutes, and the volume of sediment treated in a single pass was approximately 5 cy (Maher et al. 2005). The mixed sediment and pozzolanic agents cure significantly over several days and reach full strength within weeks.

The principal hazard of implementation is associated with mobilizing contaminated sediment during treatment. For treatment using conventional excavators, the treatment area may be isolated from the surrounding surface water and standing water would be removed prior to treatment, which effectively controls potential releases of contaminated sediment (Peckhaus 2011). Soil-mixing augers create minimal disturbance of shallow sediment. Extensive testing of turbidity and total suspended solids was performed during a demonstration of S/S using deep soil mixing augers in Newark Bay (Maher et al. 2005). The testing found no impacts in the top one-third of the water column. In the middle one-third of the water column, turbidity and suspended solids impacts were limited to within 125 feet of the deep soil mixing augers, and even in the bottom one-third of the water column, the water quality impacts were limited to within 135 feet of the augers.

S/S treatment by itself would control resuspension of contaminated sediment and desorption of dioxin from sediments. If dredging were required in the future, such as for navigation, S/S is also beneficial in that the treated sediment is less likely than untreated sediment to be resuspended during dredging. Short-term risks associated with implementing the technology are limited and readily monitored. Operations could be modified, if warranted, to further reduce short-term impacts.

3.5.3 Implementability

The materials required for S/S are readily available. Portland cement is a common construction material. Fly ash and cement kiln dust, which are often less expensive alternatives to Portland cement, are byproducts of electrical power production and cement production may be available. The use of specialized equipment, such as soil-mixing augers, may be the best option for implementing S/S in areas of the Site with deeper water, such as in the navigation channel. This equipment is not as readily available as conventional excavators.

Permits are not required for on-site CERCLA actions. The technical requirements of regulations for the protection of water quality would be met through the use of appropriate equipment and BMPs. Water-quality monitoring would be performed to detect impacts and adjust practices as needed.

3.5.4 Cost

The review of S/S use for Superfund remedial actions (USEPA 2000b) reported the average cost for 29 completed projects was more than $260 per cy and the average cost, excluding two projects with very high costs, was just under $200 per cy. The wording of the text in the report suggests that these figures are the quotient of the total project costs divided by the volume of material treated. The actual costs for S/S are less than these figures suggest. The costs for two recent Gulf Coast S/S projects were reviewed. The average unit cost to stabilize shallow material in the Western Cell during the TCRA using Portland cement was approximately $25 per cy. The cost for solidification using fly ash and conventional excavators on a Gulf Coast project completed in 2009 was also approximately $25 per cy. If a unit weight of 1.4 tons per cy were assumed for the sediments, the range of unit costs for these two projects is approximately $35 per ton. Costs for S/S using specialized equipment would be higher.

3.5.5 Recommendation

S/S is a potentially applicable technology for the remedial action at the Site. Sufficient information is available from investigations and full-scale remedial actions at other sites to evaluate remedial alternatives that incorporate this technology. Therefore, site-specific treatability testing is not necessary for the FS. If a remedy using S/S is selected, then site-specific treatability testing should be performed as part of the remedial design to identify appropriate solidification reagents and admixture ratios and to confirm the permeability and leaching characteristics of the treated sediment.

4 SUMMARY AND CONCLUSIONS

This document presents treatment technologies that are considered potentially applicable to the contaminated material detected at the Site. All ex situ treatment methods would require mechanical removal of the potentially contaminated materials, and the treatment itself would be performed off-site, as the Site is located within the River and adjacent floodplain. Depending on the method selected, there are additional facilities that would need to be established near the Site prior to execution of the treatment (e.g., berthing; loading and unloading; and material stockpiling and dewatering). The addition of such facilities would need to occur prior to implementation of the remedy, thus a method that would use these facilities would require sufficient construction lead-time factored into the implementation schedule. Additionally, ex situ treatment would require the establishment of appropriate facilities off-site, except in the case of incineration, for which a commercial facility that can treat material from the Site is available. The establishment of an off-site treatment facility would require acquiring land, obtaining permits, and building treatment and support facilities. Lastly, should the contaminated material within the TCRA Site require ex situ treatment, an assessment of the risks and costs associated with the removal, treatment, and disposal of the stabilization components would be necessary. As described in Section 1.3.2, these operations also require the establishment of an off-site location for transloading, staging, and decontaminating the armor rock material. The costs for these operations are not included in this evaluation.

Table 4-1 presents a summary of the evaluation of potential treatment technologies. The following technologies are potentially applicable to the Site:

- Incineration
- IPTD
- Chemical Dehalogenation (BCD and SET)
- Adsorbent Technologies (including AC and organoclay)
- S/S

Table 4-1
Treatment Technology Screening Matrix

Technology	Screening Criteria					Vendor Contacted[7,8]	Alternative Retained for Detailed Evaluation[9]
	Effectiveness[1,2]	Implementability[3]	Feasible Alternative	Relative Unit Cost[4,6]	Regulatory Requirements[5]		
Thermal Treatment							
Incineration	Yes - Incineration is a proven full-scale technology for dioxin destruction	Yes - Facility available for treatment of sediment, sludge, and water	Yes	$900/ton	Loading/unloading facility permits are necessary; Incineration permits retained by Veolia Environmental Services	Yes - Veolia Environmental Services	Yes
In-Pile Thermal Desorption	Yes - In-Pile Thermal Desorption is a proven full-scale technology for dioxin destruction	Yes - Equipment is available for application; Facility needs to be established for treatment	Yes	$350-$520/ton	Loading/unloading facility permits are necessary; Treatment site permits are necessary prior to implementation	Yes - TerraTherm, Inc.	Yes
Dehalogenation							
Polyethylene Glycolate	Uncertain - Polyethylene Glycolate reagents (Alkaline and Potassium) have been successfully applied to PCBs	No - Vendors and recent applications were not available	No	N/A	N/A	No	No
Solvated Electron Technology	Yes - Solvated Electron Technology has been successfully applied to PCBs and dioxins	Yes - Vendor is available and has tested the technology at pilot-scale; application to dioxins is certain	Yes	N/A	Loading/unloading facility permits are necessary; Treatment site permits are necessary prior to implementation	Yes - Commodore Advanced Sciences, Inc.	Yes
Base-Catalyzed Decomposition	Yes - Base-Catalyzed Decomposition is a proven technology; no full-scale applications are currently being conducted conducted in the U.S.	No - Vendors listed in documentation are no longer available and no company is currently permitted to apply this technology in the U.S.; application to dioxins is certain	Yes	$1,037-$1,220/ton	Loading/unloading facility permits are necessary; Treatment site permits are necessary prior to implementation	No	Yes
Degradation							
Photolysis (UV Degradation)	Uncertain - Complete degradation of dioxins by photolysis has not been documented	No - Equipment and personnel available for material distribution; area required for treatment would be excessive	No	N/A	N/A	No	No
Bioremediation							
Dehalococcides	Yes - *Dehalococcides* are proven effective in dehalogenating dioxins; bench-scale treatment has not been conducted	No - Equipment for treatment and testing has not been developed	No	N/A	N/A	No	No
Adsorbent Technologies							
Organoclay	Yes - Organoclay is effective in adsorbing dioxins; further site-specific testing is suggested	Yes - Equipment and personnel available for product application	Yes	$2.50-$31.90/sf	None	Yes - AquaBlok, CETCO	Yes
Activated Carbon	Yes - Activated Carbon is effective in adsorbing dioxins; further site-specific testing is suggested	Yes - Equipment and personnel available for product application	Yes	$3.70-$10.30/sf	None	Yes - AquaBlok, CETCO	Yes
Solidification/Stabilization							
Solidification/Stabilization	Yes - Solidification/Stabilization is a proven method to immobilize dioxins; necessary reagents would require further testing	Yes - Equipment and personnel available for method application; specialty equipment may be necessary for deep-water application	Yes	$35/ton	None	Yes - RECON Environmental, Inc.	Yes

Notes:
1. Those methods described as ex situ applications completely remove the contaminated source material by dredging; efficacy for these methods is considered to be complete.
2. PCB - polychlorinated biphenal.
3. Dredging operations must also consider the implementability in terms of coordinating with navigation channel traffic.
4. Treatment costs do not include the excavation of contaminated sediments, the establishment of the off-site unloading/loading facility, or transportation of the contaminated material. Additionally, these costs do not include the testing, design, and development of the treatment method.
5. Ex situ treatment will also require a permitted facility that is available to receive waste barged from the Site and that can accommodate equipment necessary to unload barges and load trucks or rail cars for delivery to the treatment site.
6. sf - square foot.
7. The license distributor, BCD Group, Inc. was contacted; however, they are not a vendor of the Base-Catalyzed Decomposition treatment technology.
8. CETCO - Colloid Environmental Technologies Company.
9. Further site-specific testing is suggested in the design phase of the project if this technology is carried forward from the Feasibility Study.

Incineration, as indicated in Section 3.1.1.5, is a full-scale technology that does not require testing for the purposes of the FS; moreover, since the facility evaluated in Section 3.1.1 has treated contaminated material from the Site, no site-specific testing would be required for evaluation of this treatment option in the FS.

The IPTD method is a full-scale technology that does not require treatability testing for the purposes of the FS; however, should IPTD be selected as a treatment option in the FS, testing the removal rate and efficacy of thermal desorption on small batches of contaminated material from the Site would be necessary as part of remedial design. Communications with TerraTherm have indicated that they can perform the necessary testing. Additionally, testing the efficacy of the IPTD treatment on materials that have been dewatered using different agents is also suggested.

The two chemical dehalogenation methods (BCD and SET) do not require treatability testing for the FS, as bench- and/or field-scale tests have proven the efficacy of these technologies to reduce dioxin concentrations in contaminated soils and sediments. While both methods may be capable of reducing dioxin concentrations in sediment to acceptable levels, the implementation of such treatment would be more difficult, and more expensive than other treatment methods that are at least as effective. If a remedial alternative that included chemical dehalogenation were selected, site-specific treatability testing would be required as part of the remedial design to determine the reagent quantity, treatment residence time, and other operating parameters necessary to reduce dioxin concentrations to acceptable levels.

Adsorbent technologies, both organoclay and AC, can effectively reduce the mobility of organic contaminants in water. No testing for the FS will be required. Should adsorbent technologies be selected as a treatment for the Site, site-specific testing will be necessary as part of a remedial design to gather performance data (e.g., removal capacity and efficiency) for each amendment.

Treatability testing for the FS is also not required for S/S, as the effectiveness of this technology has been demonstrated in successful full-scale treatment efforts and at the Site. If S/S is selected as a treatment for the remedial action, site-specific testing may be required during remedial design to determine the appropriate solidification reagents and admixture ratios and to confirm the permeability and leaching characteristics of the treated sediment under different conditions.

Lastly, unit costs per acre for each of the methods listed above are provided in Table 4-2. The cost for technologies requiring the sediments to be treated ex situ includes a general assessment of typical costs associated with establishing a transloading facility, removing the sediments by mechanical dredging, dewatering and stabilization using Portland cement, and transporting the material to an off-site location. The cost information provided below is meant to aid in the overall assessment of the potential costs expected during certain phases of the removal and treatment processes; a complete cost analysis of each specific remedial alternative will be provided in the FS. These figures are not intended to represent actual cost estimates, as the dredging, transloading, and hauling operations have anticipated an ideal facility that only requires minimal renovations and whose location is near the assumed impacted area. Moreover, the cost of renovating said facility is not included in the unit costs provided in Table 4-2. Rather, it should be expected that if an ideal facility were chosen for the transloading area, then a lump sum cost of $500,000 to $700,000 could be assumed for renovations. Additionally, when assembling the dredging and treatment unit cost information, the depth of contaminated sediment was assumed to be 3 feet and the sediment unit weight was assumed to be 1.4 tons per cy. Lastly, a facility location was also assumed to be located within 50 miles of the transloading facility and the haul rate was assumed to be $0.55 per ton-mile.

Table 4-2

Cost Ranges for Applicable Treatment Technologies

Treatment Method	Application	Areal Unit Cost Range ($ thousands/acre)	
Incineration	Ex Situ	$6,500	$7,700
In-Pile Thermal Desorption (IPTD)	Ex Situ	$2,700	$3,900
Base-Catalyzed Dehalogenation (BCD)	Ex Situ	$7,400	$8,600
Adsorbent Technologies	In Situ	$110	$1,400
Solidification/Stabilization (S/S)	In Situ	$240	$290

The final remedy for the Site could involve one or more of the treatment technologies summarized above, combined with a variety of more conventional remediation technologies.

Ultimately, those decisions will be based on the development of the remedial action objectives and goals for the Site and the outcome of the FS.

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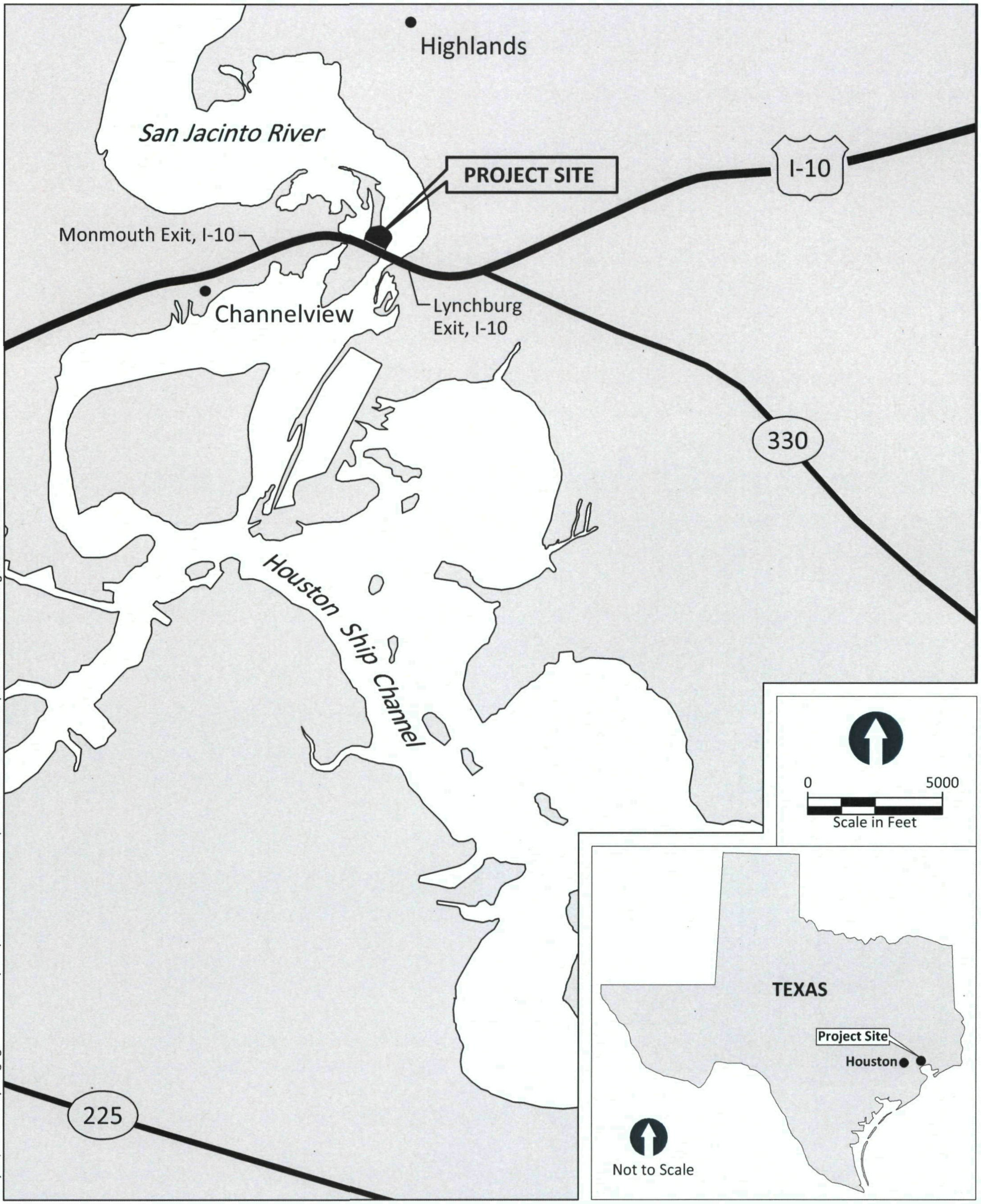
FIGURES



May 18, 2011 2:45pm tgriga K:\Jobs\090557-San Jacinto\090557-01 - San Jacinto\09055701-RP-049.dwg FIG 1-1 DTSLR

Figure 1-1
Vicinity Map
Draft Dioxin Treatability Study Literature Review
San Jacinto River Waste Pits Superfund Site

ANCHOR QEA

DRAFT

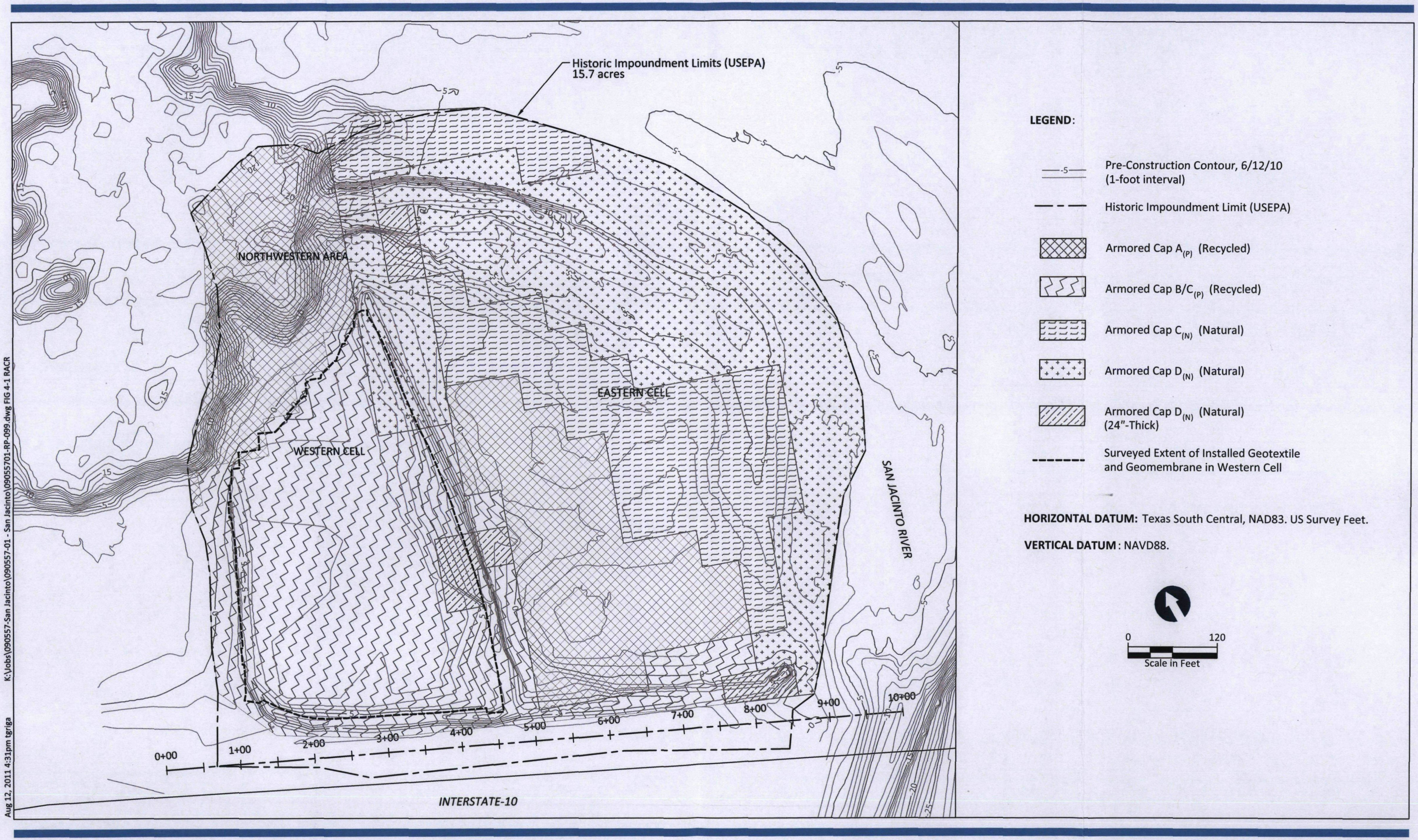


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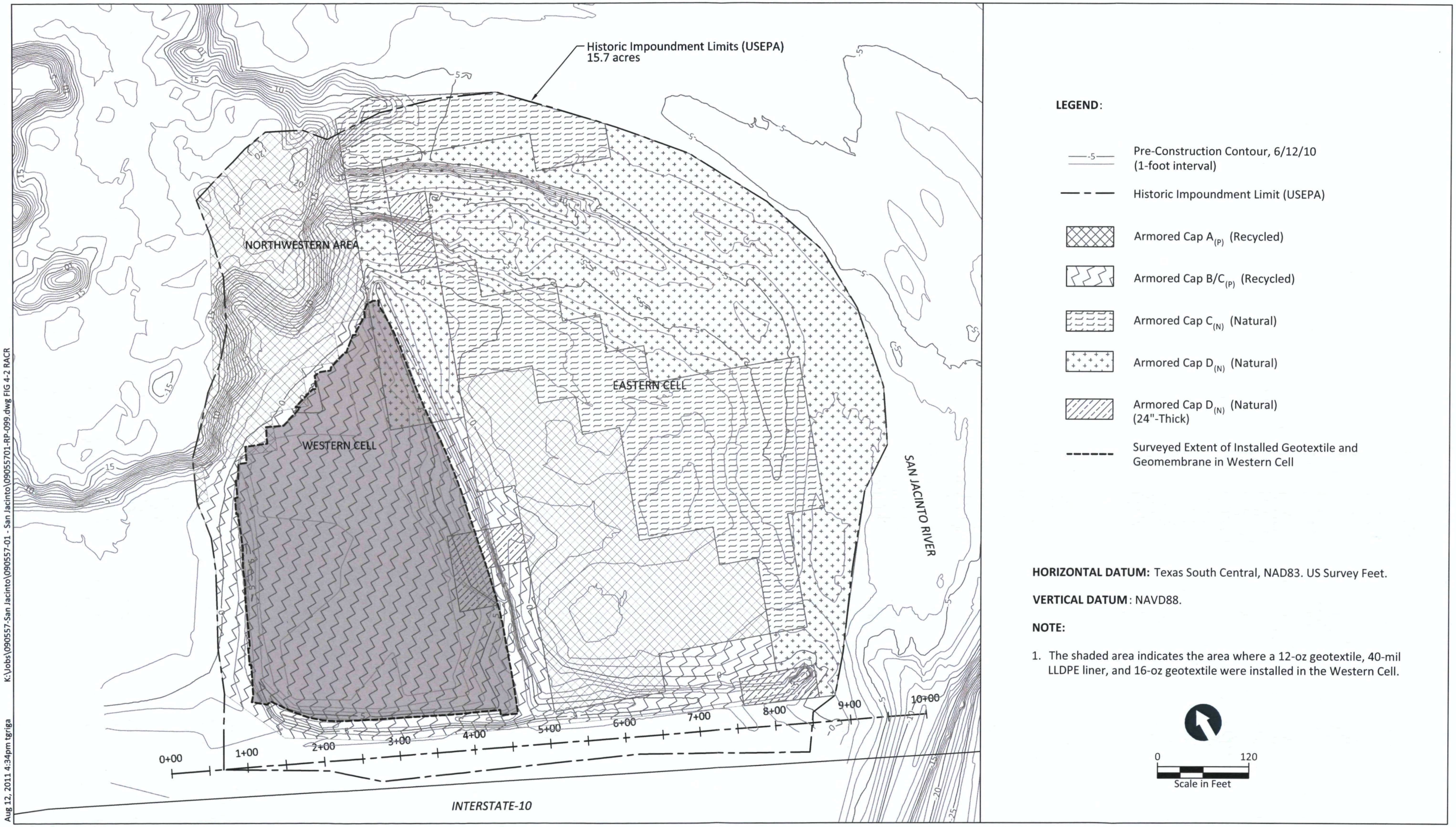
Figure 1-2
Armored Cap As-Built
Draft Dioxin Treatability Study Literature Review
San Jacinto River Waste Pits Superfund Site



Aug 12, 2011 4:34pm tgriga K:\Jobs\090557-San Jacinto\090557-01 - San Jacinto\09055701-RP-099.dwg FIG 4-2 RACR

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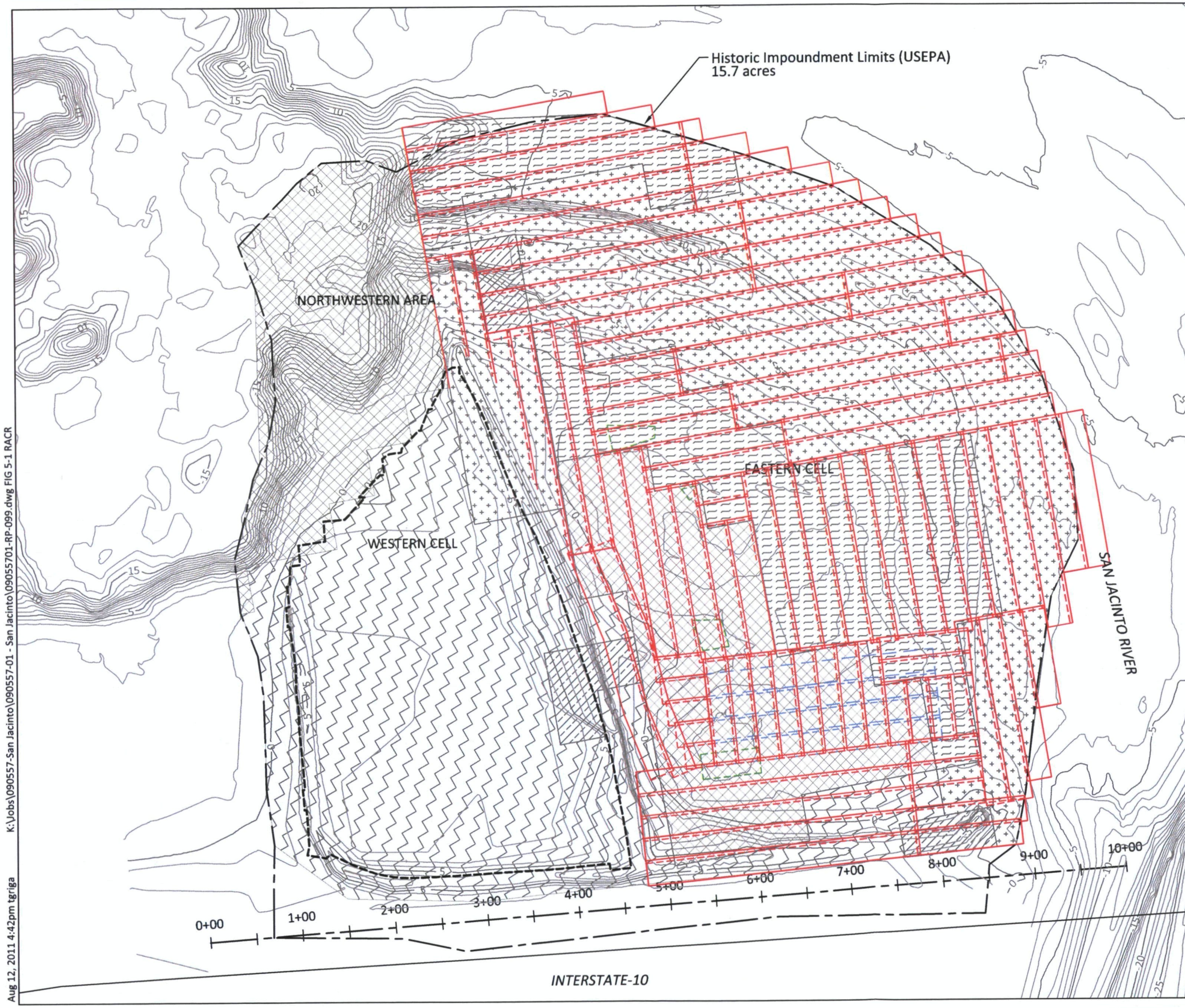
Figure 1-3
Western Cell Geotextile and Geomembrane As-Built
Draft Dioxin Treatability Study Literature Review
San Jacinto River Waste Pits Superfund Site



LEGEND:

- Pre-Construction Contour, 6/12/10 (1-foot interval)
- Historic Impoundment Limit (USEPA)
- Armored Cap $A_{(P)}$ (Recycled)
- Armored Cap $B/C_{(P)}$ (Recycled)
- Armored Cap $C_{(N)}$ (Natural)
- Armored Cap $D_{(N)}$ (Natural)
- Armored Cap $D_{(N)}$ (Natural) (24"-Thick)
- Final Geotextile Panels
- USA Installed Geotextile Panels (Underlay)
- USA Installed Geotextile Panels (Repair to Address Exposed Sediment)
- Surveyed Extent of Installed Geotextile and Geomembrane in Western Cell

HORIZONTAL DATUM: Texas South Central, NAD83. US Survey Feet.

VERTICAL DATUM: NAVD88.

NOTES:

1. Panel data from Sheet M8, titled Panel Configuration, by CRA, Inc. dated May 20, 2011.
2. The fabric panels depicted by this plat are based on information provided by the client and is not the result of an actual survey performed by CRA, Inc. The fabric panels shown are 27' wide by 300' long (maximum) with a 3' overlap along seams.
3. The berm area data shown on this plat reflect various Site conditions at the time of survey and are added for reference purposes. Please refer to specific berm survey plats for additional information.

0 120
Scale in Feet

Figure 1-4
Water-Based Geotextile As-Built
Draft Dioxin Treatability Study Literature Review
San Jacinto River Waste Pits Superfund Site

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